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Study on the Comparison of Zero Shear Viscosity and Capillary Viscosity of Road Asphalt

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The penetration and the penetration index, softening point of 60 °C and equivalent softening point, dynamic viscosity, dynamic shear rheological test, zero shear viscosity and multiple stress creep recovery modified asphalt high temperature performance of high viscosity test were evaluated; the use of penetration, low temperature ductility, equivalent brittle point and bending beam creep test on the low temperature performance was evaluated by study; penetration index PI, penetration index PVN viscosity and viscosity temperature index VTS, viscosity temperature curve of temperature sensing properties were evaluated; aging test and atomic force microscopy experiment was conducted to study the anti-ageing performance of the rolling thin film oven heating, pressure test. The stress in asphalt pavement structure based on a comparative study of the matrix asphalt, SBS, high strength, high viscosity modified asphalt and other 8 kinds of road asphalt 80 °C zero shear viscosity, capillary viscosity, and the test method of zero shear viscosity is simplified. Test and analysis show that the high viscosity modified asphalt in the first region and Newton common asphalt in pavement structure under uniform shear rate, bond properties of zero shear viscosity can be more reasonable to characterize asphalt in pavement structure.

1. Introduction

In recent decades, with the rapid development of China's economy, the rapid growth of highway traffic, mileage increased year by year, the continuous improvement of highway grade, road conditions gradually improve. The construction of the highway has greatly improved people's travel conditions, accelerated the development of logistics, and promoted the development of the society. China's highway industry has entered the high-speed development period of high grade highway (Chung, 2015). The study on the application of OGFC pavement in our country started relatively late, mainly using Japanese experience for reference (Geng et al., 2010). The reasonable test method and evaluation index of high viscosity asphalt has a direct impact on the use and production of materials, it is necessary to obtain a reasonable viscosity test method and evaluation index according to the actual stress state of the pavement (Bayarmaa and Li, 2016).

2. Comparative study on high temperature performance evaluation of high viscosity modified asphalt

2.1 Analysis of common asphalt high temperature evaluation index at home and abroad

Penetration is one of the conventional indicators reflect the high-temperature performance of asphalt. The test of the three step determination of softening point is as follows: (1) samples after heating asphalt poured into the brass ring, which is slightly higher than the torus; (2) after cooling at room temperature will be higher than the 0.5h torus like scrape, makes the surface flush with the torus (3;) pre sample estimates will be within the softening point of 70# asphalt and high viscosity modified asphalt (M), brass ring locator, steel ball and ring frame specimens placed in temperature (5±0.5)°C/min (constant temperature water bath determination of high viscosity modified asphalt softening point (H). In (32±1)°C glycerin in the same time constant C); (4) the brass ring sleeve and the steel ball is placed on the locator ring, open the instrument to ensure the heating,

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water or glycerin temperature after 3min to (5±0.5)°C/min speed increased, until the sample is heated The ball falls to soften, vertical and lower bearing plate surface contact temperature is just the softening point of asphalt samples; (5) each kind of asphalt specimens parallel determination of two results, the average value is taken as the final results. Two determination of the difference need to meet the following conditions: the softening point is less than 80 °C, the difference is less than or equal to 1 °C; softening point of 80 to 100 °C, the difference is less than or equal to 2 °C; the softening point is greater than 100 °C, the difference is less than or equal to 3 °C. This test adopts vacuum capillary viscometer for manufacturers to provide 60 °C of dynamic viscosity were verified, 70# asphalt 60 °C for simultaneous determination of dynamic viscosity (Chen, 2014).

2.2 Experimental comparison of zero shear viscosity and capillary viscosity of asphalt at high temperature

Two kinds of high viscosity modified asphalt viscosity of s 60 °C are indeed up to $1*10^5$Pa.s. The high viscosity modified asphalt (H) at three temperatures of the minimum penetration, softening point, dynamic viscosity of 60 °C, the maximum penetration of 70# asphalt, the softening point of 60 °C and the minimum, two kinds of dynamic viscosity and high viscosity modified asphalt is far from, if the penetration and softening point and 60 °C as high temperature viscosity index, two kinds of high viscosity modified asphalt high temperature performance is better than that of 70# matrix asphalt and high viscosity modified asphalt (H) best. Two kinds of high viscosity modified asphalt (H) penetration index PI and equivalent softening point T_{800} is small, the high viscosity modified asphalt (H) of these two indicators, high viscosity modified asphalt (M) of 70# asphalt minimum. To evaluate the high temperature performance of the two indicators in, with the penetration, softening point, dynamic viscosity test of 60 °C and get the same conclusion: two kinds of high viscosity modified asphalt especially high viscosity modified asphalt (H) has good high temperature stability, 70# matrix asphalt is better than the two kinds of high viscosity modified asphalt at high temperature poor performance. But note that the penetration test, dynamic viscosity test 60 °C affected by human factors are larger. According to Li Lihan et al., measurement of high viscosity modified asphalt by capillary method because of its viscosity, shear rate is very slow, the flow of time is longer, the viscosity test value is too high, cannot accurately reflect the high viscosity modified asphalt pavement viscosity characteristics (Pu et al., 2014). As mentioned earlier, the softening point of experimental measured values are higher than the softening point of the real situation so the softening, several evaluation methods for the evaluation of high temperature performance of modified asphalt with high viscosity are insufficient. The schematic diagram of the experimental apparatus is shown in Figures 1 (a) and (b).

(a)

(b)

Figure 1: (a) Schematic diagram of softening point tester and (b) Schematic diagram of vacuum capillary viscometer Evaluation of high temperature performance of high viscosity modified asphalt by dynamic shear rheological test

Dynamic shear rheological test working principle as shown in Figure 2, the asphalt specimen placed between a left and right oscillating plate and a fixed plate, vibration plate from point A to point B began to move, then turn back after A moved to C, then from C to A and complete a cycle. Dynamic shear rheological test can be stress control or strain control. When the stress is controlled, the torque in the process of rotation is kept unchanged, and the radian of the oscillation plate is slightly different, while the strain control is to keep the distance of the oscillating plate to move, and the torque is different (Cao et al., 2015). Test angle frequency is 10rad/s, approximately equal to 1.59Hz; the strain control mode of loading, the original asphalt, RTFOT asphalt control strain values were 15% and 1.2%; test of three kinds of test sample and RTFOT asphalt residues were two times the dynamic rheological experiments, measure the complex shear modulus G* and phase angle, the rut factor G*. The test temperature is 52°C, 58°C, 64°C, 70°C, 76°C, 82°C, 88°C. According to the United States SHRP plan road performance classification, two kinds of high viscosity modified asphalt high temperature performance belongs to PG76; 70# matrix asphalt high temperature performance belongs to PG64. If the PG classification as a basis for evaluation, cannot distinguish between two kinds of high viscosity modified asphalt high temperature performance difference. The relationship between rutting factor and temperature change before and after the three kinds of asphalt is shown in Figure 3 and figure 4. With the increase of temperature, the rutting factor of the three kinds of asphalt decreased continuously, and the range of decrease was larger in the relatively low temperature range. This shows that the rutting resistance of asphalt becomes worse with the increase of temperature. Three kinds of asphalt in the short term after aging, rutting factor have been improved, indicating that the short-term aging of asphalt anti rutting ability can be improved. Two kinds of high viscosity modified asphalt at the same temperature rutting factor before and after aging was much higher than that of 70# matrix asphalt and high viscosity modified asphalt (H) of the rutting factor high viscosity modified asphalt (M) is slightly larger, therefore, two kinds of high temperature performance is obviously better than that of 70# asphalt high viscosity modified asphalt.

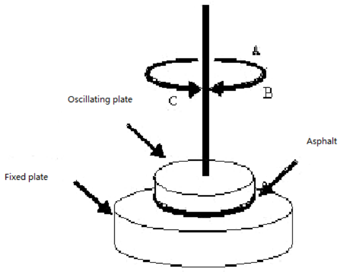

Figure 2: Schematic diagram of working principle of dynamic shear rheometer

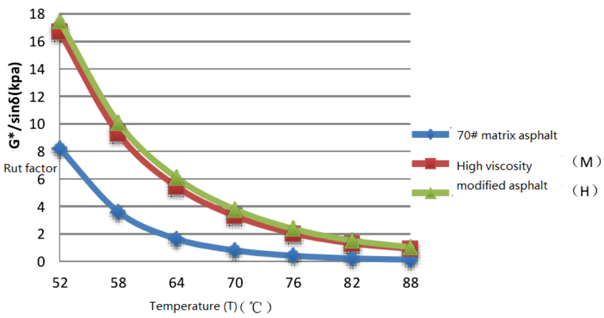

Figure 3: Three kinds of rut factor - temperature variation (Before aging)

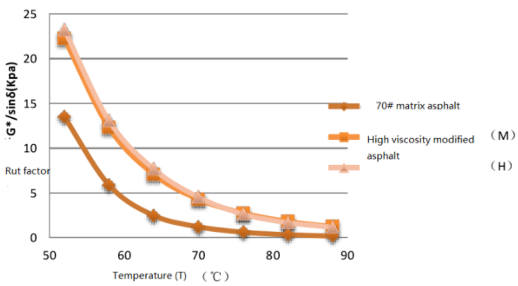

Figure 4: Three kinds of rut factor - temperature variation (After aging)

3. Test principle and test method

3.1 Evaluation of high temperature performance of high viscosity modified asphalt by zero shear viscosity

In this way, we can further study whether there is a non-Newtonian property of the viscous flow of asphalt, and then take the necessary means to determine ZSV. This experiment produced by the U.S. TA Advanced Rheometer-2000ex advanced rheometer dynamic frequency sweep test of three kinds of asphalt (Chen, 2014). Using two parallel plates with a diameter of 25mm, the plate spacing is 1mm. According to the relevant research shows that: when the frequency is 10-2~102Hz, it can simulate the normal traffic condition of the road surface, low frequency analog light traffic, high frequency simulation heavy traffic. Therefore, the frequency range of this test is 10-2~102Hz. Combined with the actual pavement temperature in summer, the strain is controlled at 60°C to be 5%, so as to ensure that the three kinds of asphalt are both within the range of online viscoelasticity.

3.2 Evaluation of high temperature performance of high viscosity modified asphalt by multiple stress creep recovery test

In 2001 the United States National Cooperative Highway Research Program in NCHRP9-10 report 459th and puts forward the method of repeated creep recovery test, intermittent simulates the actual pavement vehicle load, in order to evaluate the high temperature performance of asphalt. The test in order to ensure the asphalt in the linear viscoelastic region, suggest that stress is in the range of 30-300Pa, by loading 1s, repeated loading unloading 9s 100 cycle test of asphalt, and then through the Burgers viscoelastic model to fit the experimental results, with G_V adhesive composition creep stiffness as evaluation index. The larger the G_V is, the better the resistance to permanent deformation of asphalt is. However, some researches show that the stress and strain of the modified asphalt in the asphalt pavement are enough to reach the nonlinear region. This experiment selects 40°C, 50°C, 60°C, 70°C four temperature test, produced by the U.S. TA Advanced Rheometer-2000ex advanced rheometer multiple stress creep recovery test, the strain recovery rate of R and unrecoverable creep compliance of Jnr as evaluation index. The test uses a parallel plate with a diameter of 25mm; the plate spacing is 1mm. By using the stress control mode, 100Pa and 3200Pa were selected to carry out the continuous test at two stress levels, each stress level was repeated for 10 cycles, each cycle was 10s - loading 1s, unloading 9s. To 60°C, for example, when the stress level is increased from 100Pa to 3200Pa, strain 70# asphalt recovery rate from 2.315% to 0.367%, down 84.146%, while for high viscosity modified asphalt (M), the strain recovery rate from 95.283% to 93.450%, down 1.923% (high viscosity modified asphalt H) the strain recovery rate from 98.428% to 97.854%, down 0.583%. It is indicated that the high viscosity modified asphalt has a lower sensitivity to stress level even at high temperature, which shows a more stable state (Liu et al., 2014).

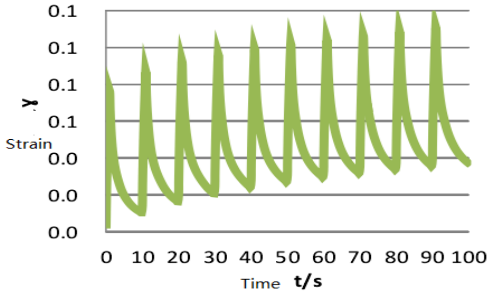

Figure 5: Strain diagram of high viscosity modified asphalt

3.3 Viscosity characteristics of road asphalt

By fluid mechanics, the fluid is divided into Newton fluid and non-Newton fluid. Newton has the fluid flow characteristics of viscosity and shear rate independent, the shear stress and shear rate, viscosity curve shown in Figure 11 shear flow curve a. Non-Newtonian fluid has the characteristics of viscosity change with shear rate, pseudo plastic fluid and plastic pseudo plastic fluid are typical non Newtonian fluid. Pseudo plastic fluid shear stress and shear rate, viscosity shear rate of flow curve 11 curve b. Plastic pseudo plastic fluid shear stress and shear rate in 11 c curve, when the material yield stress is very small, plastic pseudo plastic fluid and pseudo plastic fluid viscosity curve of shear rate of flow is very similar, see the relationship between the viscosity shear rate curve of c, see Figure 7. It is generally considered that the road asphalt material belongs to pseudo plastic fluid under the working conditions of the road, and the viscosity decreases with the increase of shear rate (Wang et al., 2016). In the limit of shear rate is very small or very large, pseudo plastic fluid viscosity close to constant region the two viscosities do not change with the shear rate called the Newtonian flow region and the second Newton flow region. The viscosity of pseudo plastic fluid flow region in the first Newton is maximum, the viscosity is called zero shear viscosity; in second the Newtonian flow region viscosity decreased to the minimum value, called infinite shear rate viscosity between the first area and the second area for Newton shear thinning region, viscosity with shear rate decreases rapidly. According to figure 6, the viscosity characteristics of road asphalt are related to the shear rate, and the viscosity decreases with the increase of shear rate (Zhu et al., 2015). The capillary tube method is very complicated to measure the flow rate curve of viscosity and shear rate. At present, the viscosity of asphalt is measured by the Newton fluid. The test principle followed Hagen Poiseuille law, asphalt viscosity and capillary flows through the capillary segment required is proportional to the time ratio is K, the capillary viscometer is calibrated by using the known fluid viscosity, the K capillary viscometer constant, can be carried out on the asphalt viscosity measurement. Shear rate scanning experiments using dynamic shear rheometer, combined with rheological model fitting analysis can obtain zero shear viscosity. The shear rate obtained by measuring the viscosity of scanning test torque and plate rotation speed, by continuously applying different torque can be obtained under different shear rate viscosity and flow curves to obtain asphalt.

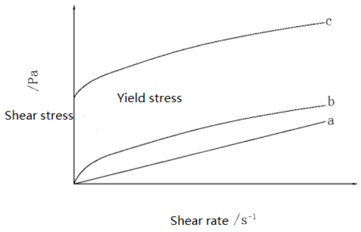

Figure 6: Relationship between shear stress and shear rate

4. Analysis and comparison of experimental results

The zero shear viscosity is generally less than the capillary viscosity, when the capillary viscosity is less than 1 * 10^5 Pa.s, is close to both in magnitude, and when the capillary viscosity greater than 1 x 10^5 Pa.s, zero shear viscosity values will be significantly lower than the capillary viscosity, 4 capillary viscosity at 10^5 Pa.s level high the viscosity of zero shear viscosity of asphalt were 10^4 Pa.s magnitude range, indicating capillary viscosity exist inflated phenomenon in the evaluation of high viscosity modified asphalt, the capillary viscosity does not match with zero shear viscosity. Further analysis of capillary viscosity can be seen, 3 ~ 12 modified asphalt capillary viscosity range of 111 * 10^4 ~ 512 *10^5 Pa.s, the maximum value is about 47 times the minimum, the distribution range is very large. In addition, the shear rate cannot be measured by capillary viscosity corresponding to the asphalt viscosity due to different test flow due to different time; different shear rate viscosity of asphalt is not the same as the corresponding. Therefore, the comparison between different asphalt viscosity is not scientific, and cannot be determined by measuring capillary viscometer test values really reflect the bonding properties of asphalt material. When the shear rate is greater than 10^{-5} s^{-1}, the 12 kinds of asphalt are characterized by pseudo plastic flow characteristics; there are obvious characteristics of the first Newtonian region, shear thinning zone, and so on. When the shear rate is less than 10^{-5} s^{-1}, the viscosity of asphalt with shear rate decreases to infinity, that road asphalt under the condition of 60°C is plastic pseudo plastic fluid characteristic, pseudo plastic fluid is not generally considered. Road asphalt is structural stiffness in the static state, if the initial minimum shear rate, shear stress is less than the yield stress of asphalt material, the flow is extremely difficult, the viscosity tends to infinity, the author of this area was named shear flow front region, referred to as the flow front area. 12 the first test of asphalt Newton common area between 110 * 10^{-3} - 10^{-2} s^{-1} magnitude, in the asphalt pavement shear rate range of 1138 * 10^{-3} – 4164*10^{-4} s^{-1}, so the 60 reflects the asphalt zero shear viscosity can be a good combination of material viscosity characteristic in the pavement structure (Xue et al., 2014). As the viscosity index of high viscosity modified asphalt is reasonable. For the matrix asphalt, the shear rate corresponding to capillary viscosity is within the range of the first Newton, so the capillary viscosity can replace the zero shear viscosity to evaluate the viscosity of the matrix asphalt. By using the Carreau model, the shear rate viscosity flow curve can be fitted. However, the use of special data analysis software Rheology Advantage to this method, and the fitting values by shear flow front area and the first Newton distinguish values were determined such as factors, cannot guarantee the fitted value of repeatability, further comparative research on the test method of zero shear viscosity. The common region of the first Newtonian region of the asphalt is between 10^{-3} – $10^{-2}$$s^{-1}$

order of magnitude, so the comparison between the average value of the 5 measurements and the zero shear viscosity in the range of 10^{-3} - 10^{-2} s^{-1}. Figure 7 shows the relationship between the zero shear viscosity and the viscosity of the Carreau model.

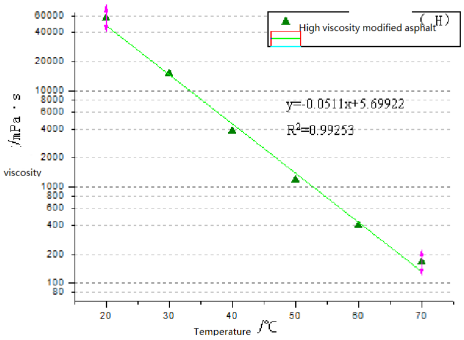

Figure 7: The relationship between the zero shear viscosity and the measured viscosity

5. Conclusions

High temperature performance evaluation index shows that the high temperature performance of asphalt is better than that of the 70# matrix of high viscosity modified asphalt, and in the short-term aging, the high temperature rutting resistance has been further improved; but the phase angle of ignoring the external discharge after the delay characteristics of a part of the gradual recovery of elastic deformation will, using phase angle to reflect the viscoelastic composition does not apply. Zero shear viscosity can be used to evaluate the high temperature performance of high viscosity modified asphalt. High viscosity modified asphalt cannot enter the viscous flow state at low shear rate, the dynamic frequency sweep test of viscosity frequency diagram extension cannot be obtained directly zero shear viscosity; zero shear viscosity using Carreau model was obtained by fitting three kinds of asphalt were able to obtain higher coefficient. The zero shear viscosity of high viscosity modified asphalt is much higher than that of 70# matrix asphalt, and it has good high temperature performance. The zero shear viscosity of high viscosity asphalt and asphalt Newton area corresponding to the first uniform shear rate range from the pavement, viscous characteristics of 60 °C can effectively characterize the zero shear viscosity of high viscosity modified asphalt in pavement structure, propose this index as the high viscosity modified asphalt viscosity evaluation key index.

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